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Assessment of wind power potential for turbine installation in coastal areas of Turkey

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ABSTRACT

This paper analyses the potential and the feasibility basis for the wind energy resources in some locations of coastal regions of Turkey. The dominant wind directions, the mean values, wind speeds, wind potential and the frequency distributions were determined. The results showed that Balıkesir and Çanakkale among annual averages show higher value of mean wind speed. The mean annual value of Weibull shape parameter k is between 1.54 and 1.86 while the annual value of scale parameter c is between 2.52 m/s and 8.34 m/s. A technical assessment has been made of electricity generation from four wind turbines having capacity of 600 kW, 1500 kW, 2000 kW and 2500 kW. The yearly energy output and capacity factor for the four different turbines were calculated.

Contents

1. Introduction

Energy is one of the essential inputs for economic development and industrialization. Fossil fuels are the main resources and play a crucial role to supply world energy demand. However, fossil fuel reserves are limited and usage of fossil fuel sources have negative environmental impacts. Therefore, management of energy sources, rational utilization of energy, and renewable energy source usage are vital [1].

Turkey is situated at the meeting point of three continents (Asia, Europe and Africa) and stands as a bridge between Asia and Europe. The demand for energy and particularly for electricity is growing rapidly, because of social and economic development of the country. In Turkey, electricity is produced by thermal power plants, consuming coal, lignite, NG, fuel oil and geothermal energy, and hydropower plants [2]. Fossil fuels provided about 86.9% of the total energy consumption of the year 2004, with oil (31.5%) in first place, followed by coal (27.3%) and natural gas (22.8%). The renewable collectively provided 13.2% of the primary energy, mostly in the form of combustible renewable and wastes (6.8%), hydropower (about 4.8%) and other renewable energy resources (approximately 1.6%) [3]. Turkey's total electricity production and installed capacity were 162.5 GWh and 38.8 MW, respectively, in 2005 [4]. The distribution of the produced electricity energy according to primary energy sources was as follows: natural gas 44.74%, hydropower 25.11%, coal 25.05%, oil 4.92%, biomass 0.09%, geothermal 0.06% and wind 0.04% [5].

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Table 1
Installed windpower capacity (MW) [18].

Country	2005	2006	2007	2008
United States	9149	9149	16,819	25,170
Germany	18,428	18,428	22,247	23,903
Spain	10,028	10,028	15,145	16,740
China	1266	1266	5912	12,210
India	4430	4430	7850	9587
Italy	1718	1718	2726	3736
France	779	779	2477	3426
United Kingdom	1353	1353	2389	3288
Denmark	3132	3132	3129	3164
Portugal	1022	1022	2130	2862
Canada	683	683	1846	2369
Netherlands	1236	1236	1759	2237
Japan	1040	1040	1528	1880
Australia	579	579	817	1494
Ireland	495	495	805	1245
Sweden	509	509	831	1067
Austria	819	819	982	995
Greece	573	573	873	990
Poland	83	83	276	472
Norway	268	268	333	428
Egypt	145	145	310	390
Belgium	167	167	287	384
Taiwan	104	104	280	358
Brazil	29	29	247	339
Turkey	**20**	**20**	**207**	**333**
New Zealand	168	168	322	325
South Korea	119	119	192	278
Bulgaria	14	14	57	158
Czech Republic	30	30	116	150
Finland	82	82	110	140
Hungary	18	18	65	127
Morocco	64	64	125	125
Ukraine	77	77	89	90
Mexico	2	2	85	85
Iran	32	32	67	82
Rest of Europe	141	204	233	261
Rest of Americas	155	159	184	210
Rest of Africa & Middle East	52	52	51	56
Rest of Asia& Oceania	27	27	27	36
World total (MW)	59,024	74,151	93,927	121,188

Wind energy is called to play a crucial role in the future energy supply of the European Union and of the world. There are now many thousands of wind turbines operating, with a total capacity of 121,188 MW of which wind power in Europe accounts for 55% in 2008 (Table 1). Based on the examination of the Wind Atlas of Turkey, it may be concluded that the regions of Aegean, Marmara, and East-Mediterranean have high wind energy potential. Turkey's annual theoretically available potential for wind power is calculated to be more than 80,000 MW, about 10,000 MW of which is also economically feasible. Annual average wind speed and annual average wind energy potential of various regions of Turkey are shown in Table 2. The annual average wind speeds range from a low value of 2.1 m/s in the East Anatolia region to a high value of 3.3 m/s in the Marmara region. The most attractive regions for wind energy applications are the Marmara, the southeast Anatolian and the Aegean regions. These regions are highly suitable for wind power generation, since the wind speed exceeds 3 m/s in most of these areas [2].

Table 2
Wind energy potential of turkey over various regions [4].

Region	Annual average wind speed (m/s)	Annual average wind density (W/m^2)
Marmara	3.3	51.9
Southeast Anatolia	2.7	29.3
Aegean	2.6	23.5
Mediterranean	2.5	21.4
Black Sea	2.4	21.3
Central Anatolia	2.5	20.1
East Anatolia	2.1	13.2
Turkey average	2.5	24.0

The starting point of any wind energy project is the resource assessment. It helps to identify suitable sites for wind turbines and also undertake an early economic cost analysis. Due to the rather large capital investment involved with wind energy projects, it is crucial to undertake the resource assessment as precisely as possible. The speed of the wind and its annual frequency are the critical parameters that determine the net output of a wind turbine [6].

In order to accurately assess wind energy potential and characteristics, it is necessary to carry out long-term meteorological observations. Wind speed is a random variable and variation of wind speed over a period of time is represented by probability density functions. Detailed knowledge of wind characteristics and distribution are crucial parameters to select optimum wind energy conversion system to optimize energy output and minimization of electricity generation cost [7]. Wind speed frequency distribution has been represented by various probability density functions such as gamma, lognormal, three parameter beta, Rayleigh and Weibull distributions. However, in recent years Weibull distribution has been one of the most commonly used, accepted, recommended distribution to determine wind energy potential and it is also used as a reference

Fig. 1. Distribution of meteorological stations over Turkey.

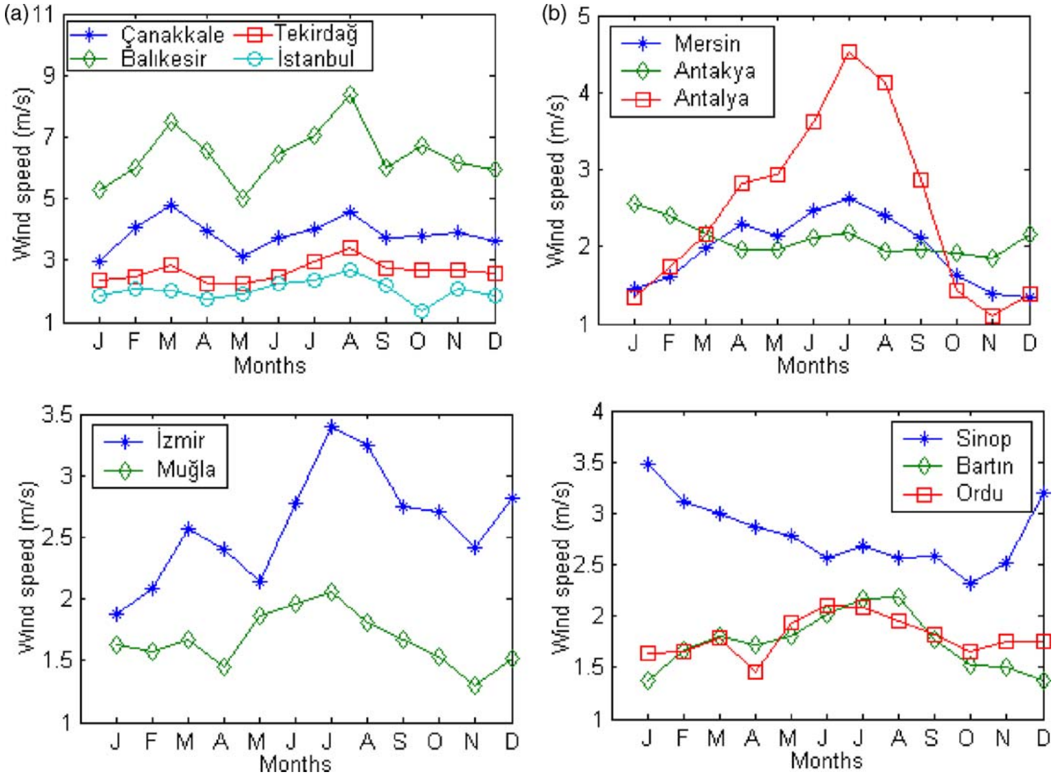

Fig. 2. Monthly variation of mean wind speeds for selected stations.

distribution for commercial wind energy softwares such as Wind Atlas Analysis and Application Program (WASP) [8].

In the last decade, a lot of studies related to the wind characteristics and wind power potential have been made in many countries worldwide. Himri et al. [9] computed the Weibull parameters for wind speed distribution at four locations namely Tindouf, Dèly Brahim, Ouled Fayet and Marsa Ben M'hidi in Algeria. The wind speed measurements data for 04 locations in Algeria for a period of 05 years have been analyzed using WASP program. The results showed that the yearly wind speed and the average wind

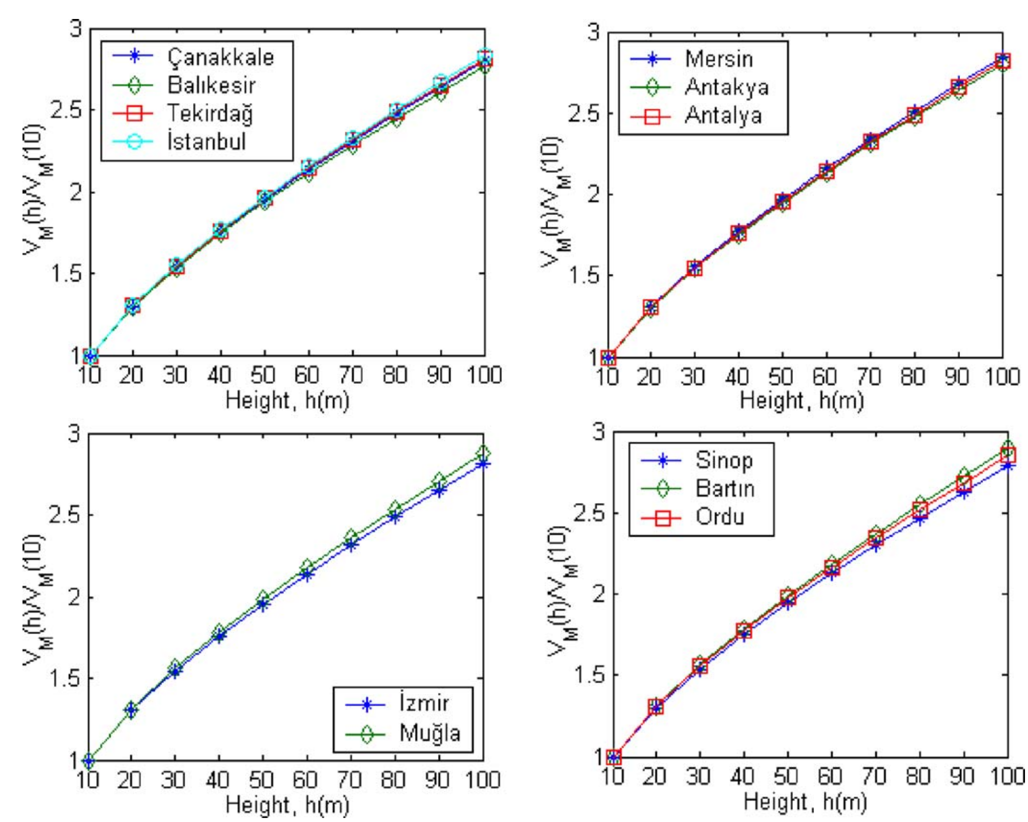

Fig. 3. Variation of the annual mean speed with the height for selected stations.

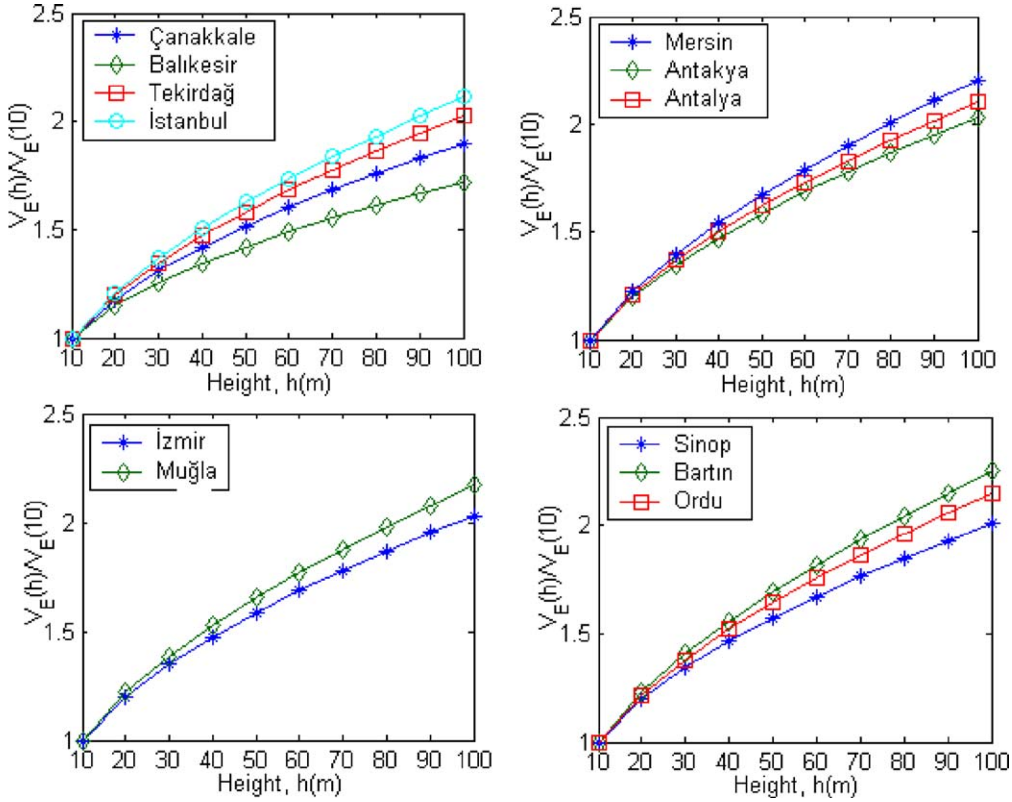

Fig. 4. Variation of the annual energy speed with the height for selected stations.

power densities are in the range of 3.9–5.8 m/s and 77–259 W/m^2 with a steady trend over the period from 2001 to 2006. Akdağ and Dinler [1] proposed a new method to estimate Weibull parameters for wind energy applications. This new method is called power density (PD) method. They compared this method with three most common methods, graphic, maximum likelihood and moment methods and numerical solution of energy pattern factor. Mahmoudi et al. [10] analyzed the feasibility of using wind energy to power brackish water greenhouse desalination units proposed for the development of the southern region of the case study country of Algeria. They determine the wind speed distributions by using the average wind speed and the available wind power for the five locations in the Sahara. The results indicated that the available wind energy is a suitable resource for power production and can be used to provide the required electricity for the brackish groundwater greenhouse desalination units. Gökçek and Genç [11] investigated the wind energy generation by using time-series approach and is to estimate the unit energy cost by means of levelised cost of electricity (LCOE) method for the various wind energy conversion systems (small and medium-scale WECS) considered for seven different sites located in the Central Anatolian Region, Turkey. Their result shows that the wind energy conversion system of capacity 150 kW produce the energy output 120,978 kWh per year in the Case-A (Pinarbasi) for hub height 30 m. Belu and Koracin [12] calculated the wind potential in western Nevada by using wind, temperature, and pressure data over a period of four and half years from four 50 m tall towers. The results show that the maximum seasonal wind speeds for all towers are during the spring. Diurnal wind speed patterns for all seasons and months showed a minimum during the late morning and a maximum during the late afternoon. Mostafaeipour [13] analyzed the wind speed of some major cities in province of Yazd which is located in central part of Iran. He determined the potential of wind power generation by using the hourly measured wind

Table 3
Characteristic speeds for selected stations at heights of 30 m, 50 m and 70 m.

Sites	α	30 m			50 m			70 m		
		V_E (m/s)	V_F (m/s)	V_M (m/s)	V_E (m/s)	V_F (m/s)	V_M (m/s)	V_E (m/s)	V_F (m/s)	V_M (m/s)
Çanakkale	0.222	10.5	4.56	7.02	12.2	5.28	8.12	13.5	5.86	9.02
Balıkesir	0.188	14.9	6.44	9.95	16.9	7.28	11.3	18.5	7.96	12.3
İstanbul	0.259	7.25	3.13	4.83	8.60	3.71	5.73	9.72	4.19	6.48
Tekirdağ	0.245	8.25	3.69	5.58	9.69	4.34	6.55	10.9	4.87	7.36
İzmir	0.246	8.16	3.66	5.52	9.59	4.30	6.49	10.7	4.83	7.29
Muğla	0.269	6.60	2.83	4.39	7.87	3.38	5.24	8.94	3.84	5.95
Antakya	0.248	8.97	5.39	2.90	10.5	3.41	6.34	11.8	3.84	7.12
Mersin	0.261	7.28	2.95	4.74	8.64	3.50	5.63	9.78	3.96	6.37
Antalya	0.257	7.39	3.17	4.91	8.75	3.76	5.82	9.88	4.24	6.58
Sinop	0.242	8.70	3.71	5.77	10.2	4.35	6.77	11.4	4.87	7.59
Bartın	0.281	5.85	2.46	3.86	7.03	2.96	4.65	8.03	3.38	5.31
Ordu	0.279	5.85	2.58	3.93	7.03	3.10	4.73	8.03	3.54	5.39

speed data at 10 m, 20 m and 40 m height for Yazd. It was found that most of the stations have annual average wind speed of less than 4.5 m/s which is considered as unacceptable for installation of the wind turbines. City of Herat has higher wind energy potential with annual wind speed average of 5.05 m/s and 6.86 m/s, respectively, at height of 10 m and 40 m above ground level. In this study, the aim is to calculate the wind energy potential in coastal regions of Turkey to assess wind electricity production of these regions. The present study reports recently collected wind data analysis at 12 locations namely Çanakkale, Balıkesir, İstanbul,

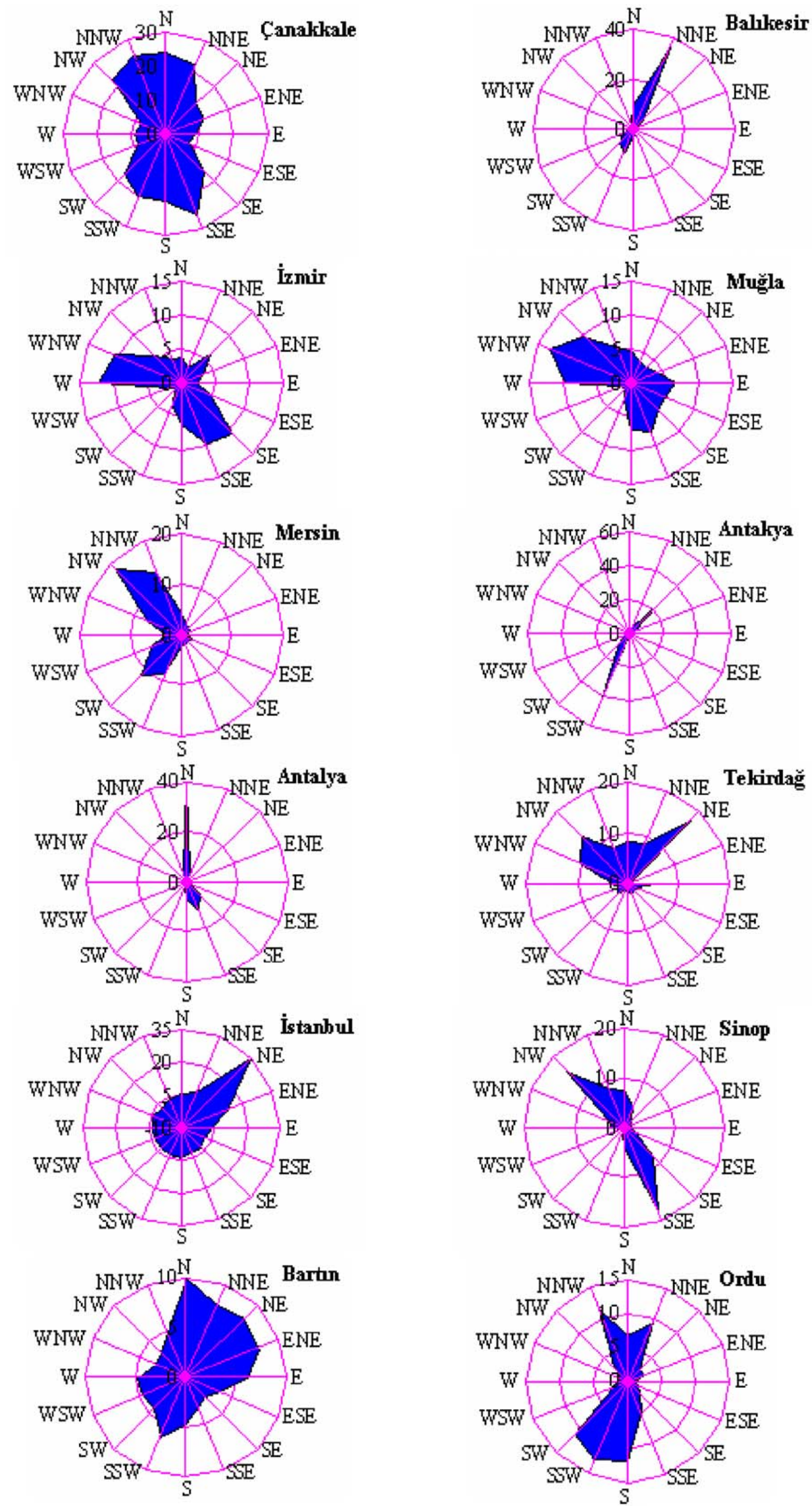

Fig. 5. Frequencies (%) of wind directions at all stations.

Tekirdağ, İzmir, Muğla, Antakya, Mersin, Antalya, Sinop, Bartın, and Ordu in Turkey.

2. Site description

The Republic of Turkey, located in Southeastern Europe and Southwestern Asia (that portion of Turkey west of the Bosporus is geographically part of Europe), has an area of about 780,580 km^2 and a population of over 70 million. Turkey's primary energy sources include hydropower, geothermal, lignite, hard coal, oil, natural gas, wood, animal and plant wastes, solar and wind energy [4]. Although Turkey is situated in large Mediterranean geographical location where climatic conditions are quite temperate, diverse nature of the landscape, and the existence in particular of the mountains that run parallel to the coasts, result in significant differences in climatic conditions from one region to the other. While the coastal areas enjoy milder climates, the inland Anatolian plateau experiences extremes of hot summers and cold winters with limited rainfall. Marmara, Aegean and Mediterranean Coasts have a typical Mediterranean climate with hot summers and mild winters. The swimming season becomes shorter as one travels north. Because of the mountains, the east side of the Aegean and the North side of the Mediterranean could have regionally different climate.

The wind speed data were measured as hourly by Turkish State Meteorological Service for the 12 stations used in this study. The geographical locations of these stations are shown in Fig. 1. All measurements at all the wind observation station are recorded using the cup anemometer at a height of 10 m above the ground level.

3. Wind speed frequency distribution

Knowledge of the wind speed frequency distribution is a very important factor to evaluate the wind potential in windy areas. If ever the wind speed distribution in any windy site is known, the power potential and the economic feasibility belonging to the site can be easily obtained. Wind data obtained with various observation methods has the wide ranges. Therefore, in the wind energy analysis, it is necessary to have only a few key parameters that can explain the behavior of a wide range of wind speed data. The simplest and most practical method for the procedure is to use a probability distribution function. There are several probability density functions, which can be used to describe the wind speed frequency curve.

The Weibull distribution is the most commonly used statistical distribution for describing wind speed data. Weibull distribution is a good match with the experimental data. The idea is that only annual or monthly average wind speeds are sufficient to predict the complete frequency distribution of the year or the month [14].

The Weibull distribution function which is a two-parameter distribution can be expressed as

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

where v is the wind speed, c is a Weibull scale parameter and k is a dimensionless Weibull shape parameter. The cumulative probability function of the Weibull distribution is given as follows

$$F_W(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

In order to estimate Weibull k and c parameters, numerous methods have been proposed over last few years. In this study, the two parameters of Weibull are determined by using mean wind speed-standard deviation method [15]

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (1 \le k \le 10) \quad \text{and} \quad c = \frac{\bar{v}}{\Gamma(1+1/k)} \tag{3}$$

The characteristic speeds of the studied site (V_m, V_E and V_F) can be by the following relations [16]

$$V_m = A\Gamma\left(1+\frac{1}{k}\right) \tag{4}$$

$$V_E = A\left(1+\frac{1}{k}\right)^{1/k} \tag{5}$$

$$V_F = A\left(1-\frac{1}{k}\right)^{1/k} \tag{6}$$

where Γ is the defined gamma function, for any reality x positive not null, by

$$\Gamma(x) = \int_0^{+\infty} t^{x-1} e^{-t} dt \tag{7}$$

The standard wind speed height extrapolation equation [12] is

$$V = V_0\left(\frac{h}{h_0}\right)^{\alpha} \tag{8}$$

where V_0 is the original wind speed at the height (h_0), V is the wind speed to be determined for the desired height, and α is the power law exponent, which depends on the surface roughness and atmospheric stability. The value of α could also be obtained from the following formula [13]

$$\alpha = \frac{0.37 - 0.088 \ln V_{10}}{1 - 0.088 \ln (h_0/10)} \tag{9}$$

Table 4
Available wind energy for each station.

Sites	k	c (m/s)	Power density (W/m^2)	Longitude	Latitude	Altitude (m)	Region
Çanakkale	1.83	5.46	179.0	26°24′E	40°08′N	3.0	Marmara
Balıkesir	1.82	8.34	647.5	27°53′E	39°39′N	101.0	Marmara
İstanbul	1.80	3.40	42.18	29°00′E	41°00′N	91.0	Marmara
Tekirdağ	1.86	4.10	74.20	27°31′E	40°59′N	3.0	Marmara
İzmir	1.85	4.04	74.02	27°08′E	38°25′N	25.0	Aegean
Muğla	1.81	3.00	28.11	28°22′E	37°15′N	646.0	Aegean
Antakya	1.54	3.93	85.77	36°10′E	36°14′N	85.0	Mediterranean
Mersin	1.74	3.32	40.64	34°36′E	36°51′N	6.0	Mediterranean
Antalya	1.82	3.48	41.29	30°45′E	36°52′N	43.0	Mediterranean
Sinop	1.79	4.28	75.06	35°11′E	42°01′N	32.0	Black Sea
Bartın	1.78	2.52	17.70	32°20′E	41°38′N	25.0	Black Sea
Ordu	1.84	2.58	18.49	37°53′E	41°00′N	10.0	Black Sea

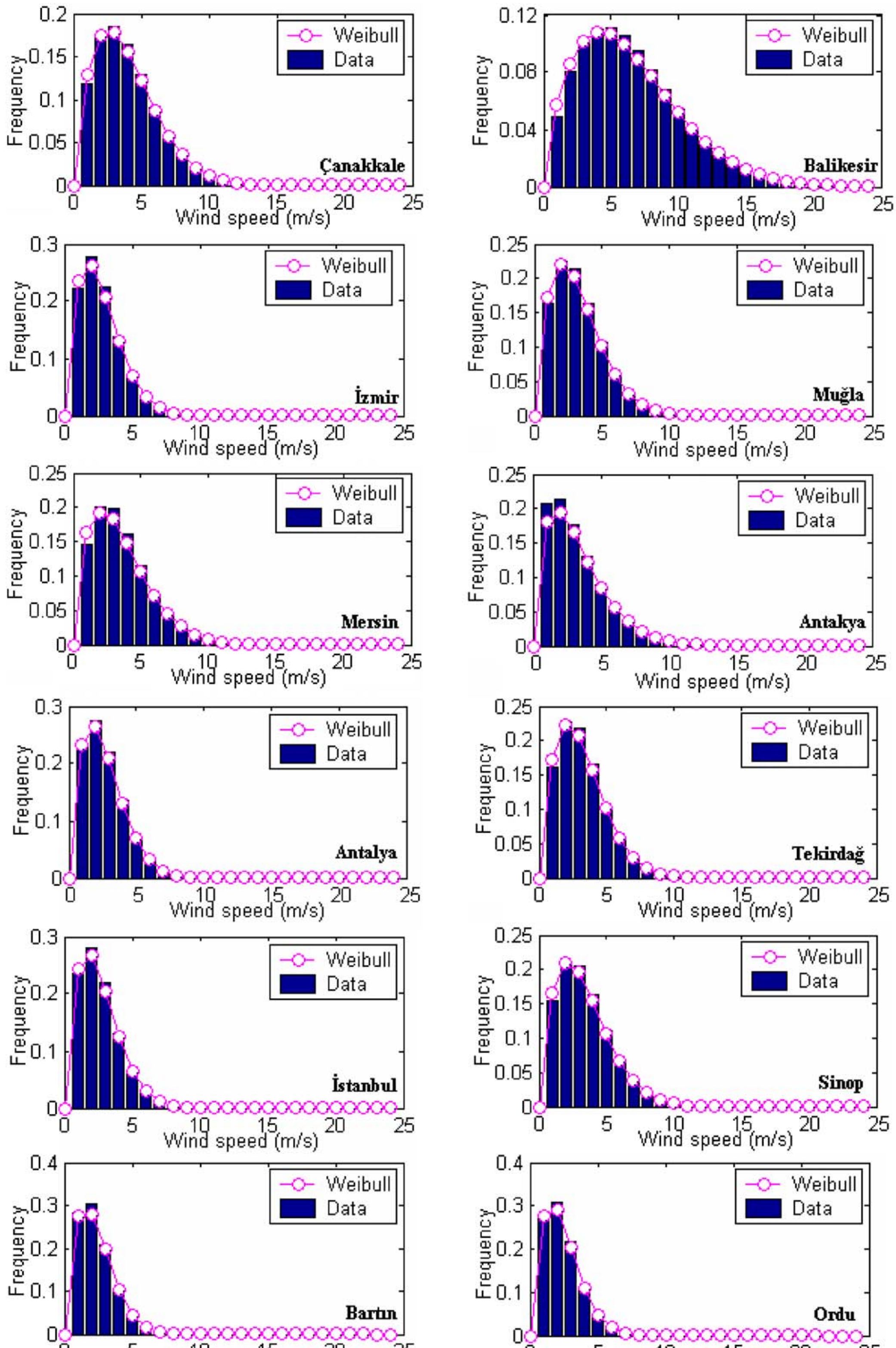

Fig. 6. Estimated annual frequency distributions of wind speed of stations.

The power of wind can be estimated by using the following equation [17]

$$P(\upsilon) = \frac{1}{2}\rho A\bar{\upsilon}^3 \quad (10)$$

where ρ is mean air density, υ^3 is mean value of the third power of the wind speed and A is sweep area. The average wind power density of site based on Weibull probability density function can be expressed as

$$P_m = \frac{1}{2}\rho\bar{\upsilon}^3 \frac{\Gamma(1+(3/k))}{[\Gamma(1+(1/k))]^3} \quad (11)$$

The capacity factor C_f is one of the performance parameters of wind turbines which both the user and manufacturer need to know. It represents the fraction of the total energy delivered over a period, E_{out}, divided by the maximum energy that could have been delivered if the turbine was used at maximum capacity over the entire period, $E_r = 8760Pr$. The capacity factor C_f of a wind turbine can be calculated as [14]

$$C_f = \frac{E_{out}}{E_r} \quad (12)$$

4. Results and discussion

4.1. Monthly mean wind speed distributions

Wind speed is the most important aspect of the wind resource; in fact the yearly variation of long-term mean wind speed provides an understanding of the long-term pattern of wind speed and also gives confidence to an investor on the availability of wind power in coming years [9].

Fig. 2 shows the monthly variation of mean wind speeds at a height of 10 m during entire data collection period for 12 stations under consideration in this study. It is seen from Fig. 2 that Balıkesir has the maximum mean wind speed of 8.35 m/s in month of August while Bartın has the minimum wind speed of 1.4 m/s in month of January. Fig. 2a illustrates the wind distribution of the districts located in the Marmara region of Turkey. It is also noticed that the localities situated in the Marmara region are characterized by a good wind potential compared to other coastal localities. Balıkesir and Çanakkale among annual averages show higher value of wind speed, and thus can be rated a better choice for wind energy utilization in comparison to other coastal localities.

Figs. 3 and 4 represent variation of the annual mean speed and energy speed with the height for selected stations. The plotted curves are comparable and they present, for a given height, almost the same profits of speed (mean and most energetic). It is clear from the figures that the mean wind speed and energy speed increase with hub height.

Table 3 gives an estimate of parameter α, mean speed and the most energetic speed at three heights (30 m, 50 m and 70 m) for selected sites. It is seen from the table that the effect of the height on the wind speed characteristics. The annual mean wind speed for Çanakkale, Balıkesir, Tekirdağ and İstanbul is found to be 9.02 m/s, 12.3 m/s, 7.36 m/s and 6.48 m/s at 70 m height, respectively. The annual mean wind speed for the cities in Mediterranean region varies between 6.37 m/s and 7.12 m/s while the cities in Black Sea region have annual mean wind speed in the range between 5.31 m/s and 7.59 m/s. The annual mean wind speed for İzmir and Muğla is calculated to be7.29 m/s and 5.95 m/s.

4.2. Wind direction

Usually, in wind data analysis, the prediction of the wind direction is also very important, especially when planning the installation and the micrositting of a wind turbine or a wind farm [14]. The relative frequencies of wind directions for the 12 stations are demonstrated in Fig. 5. According to this figure, the most windward directions at İzmir and Muğla are west and west-north-west, while the most windward direction at Mersin and Antalya are north-west and north, respectively. The highest percentage of windward direction is obtained from the south-south-west direction, it is 40.93% and it was recorded in Antakya. The lowest percentage of windward direction is obtained from the north direction, it is 9.93% and it was recorded in Bartın. The most

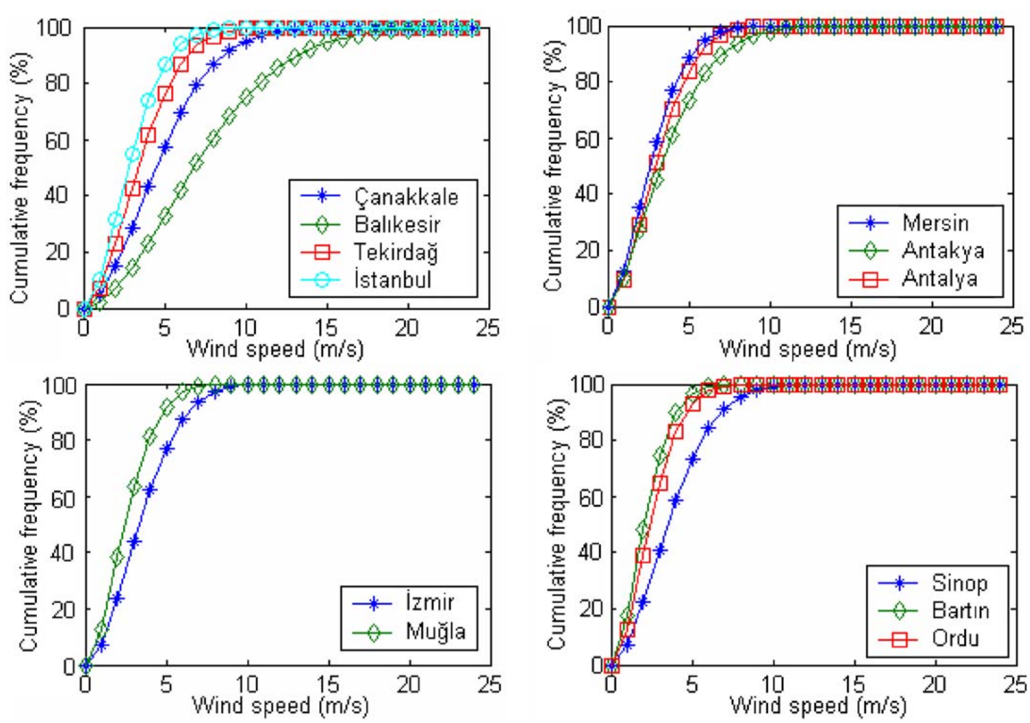

Fig. 7. Wind speed cumulative probability distributions for selected stations.

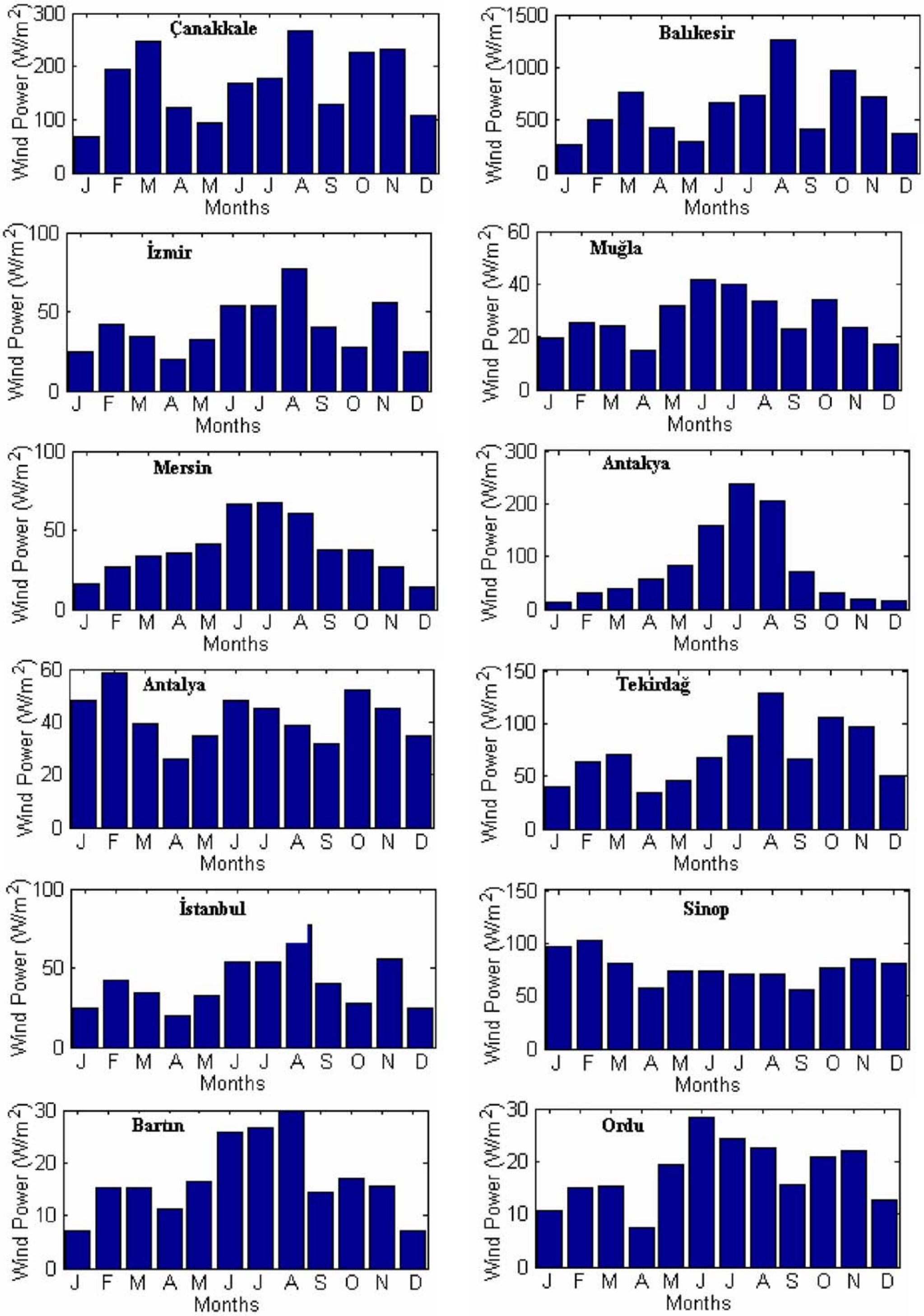

Fig. 8. Monthly variation of the mean power density.

Table 5
Main characteristics of four different commercial wind turbines [19–21].

Characteristics	Suzlon S52-600 kW	Suzlon S82-1.5 MW	Vestas V80-2.0 MW	Nordex N80-2.5 MW
Hub height (m)	75	78.5	67	70
Rated power *Pr* (kW)	600	1500	2000	2500
Sept area (m^2)	2124	5281	5027	5026
Cut-in wind speed V_{ci} (m/s)	4	4	4	3
Rated wind speed V_r (m/s)	13	14	16	15
Cut-off wind speed V_{co} (m/s)	25	20	25	25

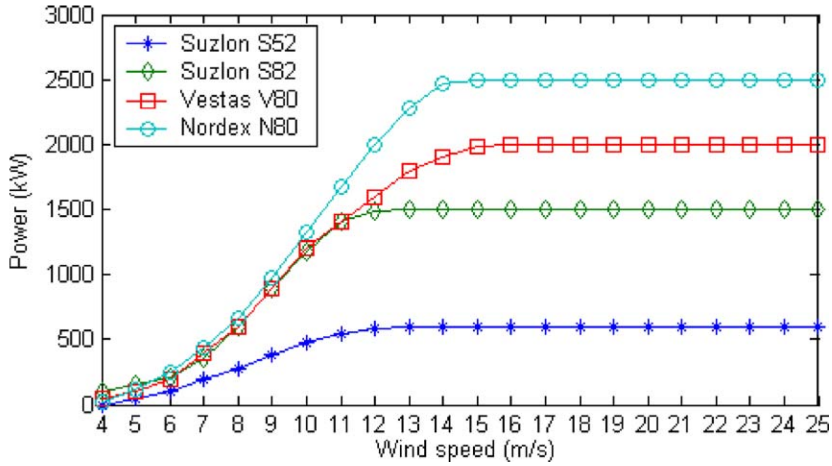

Fig. 9. Power curves for the selected wind turbines.

windward directions in the northern part of Turkey are south-south-east, south-south-west and north. In the Marmara region of Turkey, the most frequent wind directions are north-east and south-south-east.

4.3. Wind speed frequency distribution and wind power analysis

Monthly values of the Weibull parameters, the power density and geographical data of the selected stations are summarized in Table 4. As seen from this table, Weibull shape parameter k varies between 1.54 and 1.86, while scale parameter c varies between 2.52 m/s and 8.34 m/s. The lowest k value is in the city of Antakya and the highest value is in the city of Tekirdağ.

The estimated annual frequency distributions of wind speed for the 12 stations are shown in Fig. 6. The peak frequencies of all the stations are shifted towards the higher values of mean wind speed. The cities of Çanakkale, Balıkesir, Tekirdağ and İstanbul in the Marmara region have frequencies of the order of 91%, 95%, 85.9% and 80% respectively, for speeds greater than or equal to 3 m/s cut-in wind speed, which contributes to the generation of electricity from wind. The cities in Mediterranean region have peak frequencies in the range between 78% and 80.6% while the cities in Black Sea region have peak frequencies in the range between 67% and 86%. The cities of İzmir and Muğla have frequencies of the order of 85% and 75%, respectively, for speeds greater than or equal to 3 m/s cut-in wind speed.

The wind speed cumulative probability distributions obtained from Weibull probability density functions for the selected stations are shown in Fig. 7. It is seen that all the curves have a similar tendency of wind speeds on cumulative density.

Fig. 8 shows monthly variation of the mean power density for the selected stations. Balıkesir has the highest annual mean power density with a value of 1257 W/m^2 in August while Bartın has the lowest with 7.01 W/m^2 in January. The yearly mean wind power density for Antakya varies from 13.8 W/m^2 to 237 W/m^2 while the yearly mean wind power density for Sinop varies from 58 W/m^2 to 96.5 W/m^2.

4.4. Wind power of selected turbines and energy output

The characteristic properties of the selected wind turbines are given in Table 5. The power curves for the four turbines with different rated power are shown in Fig. 9. The rated powers of these turbines were 600 kW, 1500 kW, 2000 kW and 2500 kW.

Fig. 10 shows the relation between the yearly energy output for the four wind turbines of capacity 600 kW, 1500 kW, 2000 kW and 2500 kW for the 12 stations. In case of wind turbine with a capacity of 600 kW (Suzlon S52), the maximum accumulated annual wind energy in the considered stations ranges from 549 MWh (in Bartın station) to 3047 MWh (in Balıkesir station) per year. In case of wind turbine with a capacity of 1500 kW (Suzlon S82), the annual energy output range from 1186 MWh/year to 5896 MWh/year. It is seen from this figure that the maximum annual energy is derived from wind turbine with a capacity of 2500 kW (Nordex N80) in Balıkesir station. The annual energy gain and capacity factor of four different wind turbines for all the stations is given in Table 6. The capacity factor of Suzlon Nordex N80-2.5 MW in Balıkesir is 32.4% while it is 37.2% for Suzlon S52-600 kW. The capacity factor of Suzlon Nordex N80-2.5 MW used in Mersin is 5.2% while it is 4.7% for Suzlon S52-600 kW. The lowest value of capacity factor is

Table 6
Annual energy gain and capacity factor of four different wind turbines for all the stations.

Station	Suzlon S52-600 kW		Suzlon S82-1.5 MW		Vestas V80-2.0 MW		Nordex N80-2.5 MW	
	E_{out} (MWh/year)	C_f	E_{out} (MWh/year)	C_f	E_{out} (MWh/year)	C_f	E_{out} (MWh/year)	C_f
Çanakkale	883.532	0.1681	1919.140	0.1461	1979.602	0.1130	3275.710	0.1496
Balıkesir	1952.353	0.3715	4262.926	0.3244	4804.650	0.2742	7087.714	0.3236
İstanbul	247.081	0.0470	530.922	0.0404	541.662	0.0309	1120.517	0.0512
Tekirdağ	410.237	0.0781	880.463	0.0670	894.914	0.0511	1677.554	0.0766
İzmir	395.359	0.0752	848.254	0.0646	861.843	0.0492	1626.359	0.0743
Muğla	164.096	0.0312	352.596	0.0268	359.841	0.0205	813.1638	0.0371
Antakya	493.746	0.0939	1080.241	0.0822	1134.629	0.0648	2055.451	0.0998
Mersin	248.560	0.0473	536.073	0.0408	550.570	0.0314	1137.635	0.0519
Antalya	266.262	0.0507	572.354	0.0436	584.252	0.0333	1190.341	0.0544
Sinop	488.579	0.0930	1053.366	0.0802	1078.013	0.0615	1960.515	0.0895
Bartın	90.852	0.0173	195.435	0.0148	199.885	0.0113	519.559	0.0236
Ordu	91.412	0.0174	196.081	0.0149	199.495	0.0114	518.464	0.0237

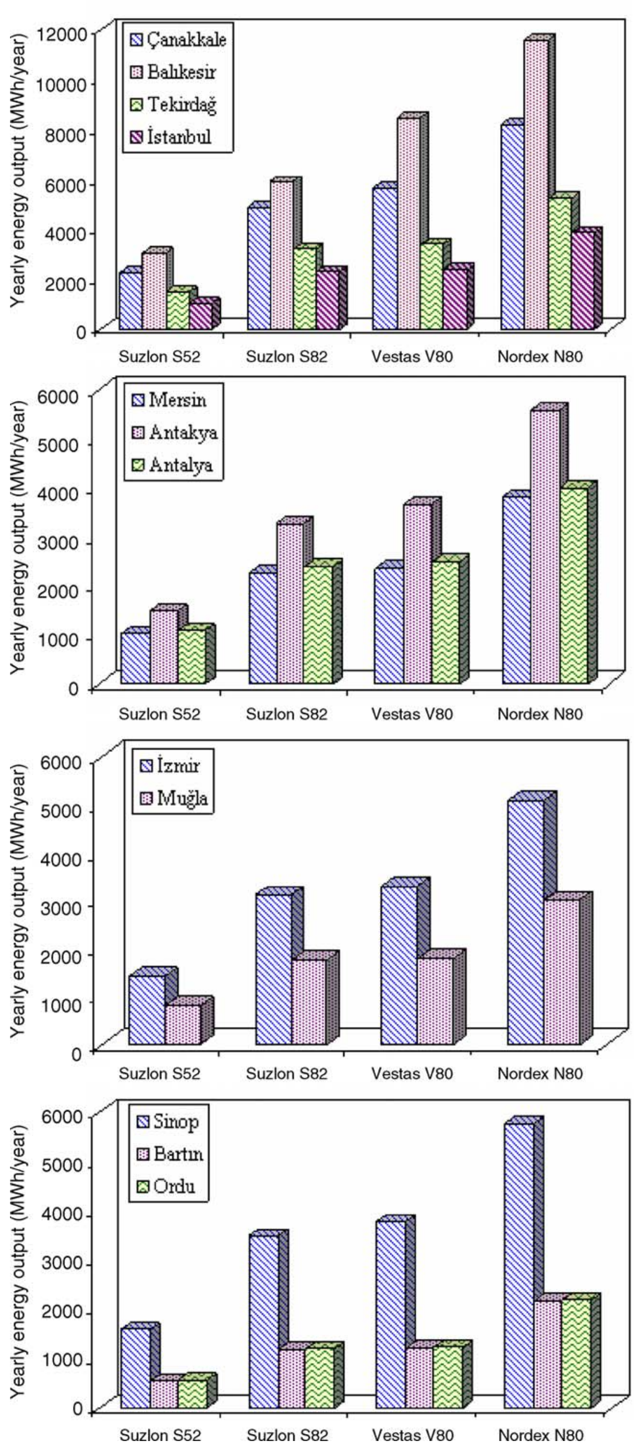

Fig. 10. Yearly energy output from four wind turbines.

calculated as 1.13% for Vestas V80-2.0 MW in the case of Bartın station at 67 m hub height. The highest capacity factor is also estimated as 37.2% in Balıkesir using Suzlon S52-600 kW at 75 m hub height.

5. Conclusion

In this study, the wind energy potential of 12 locations in coastal regions of Turkey was calculated. The following conclusions can be drawn from the results of the present study:

(1) Balıkesir has the maximum mean wind speed of 8.35 m/s in month of August while Bartın has the minimum wind speed of 1.4 m/s in month of January. The annual mean wind speed for the cities in Mediterranean region varies between 6.37 m/s and 7.12 m/s while the cities in Black Sea region have annual mean wind speed in the range between 5.31 m/s and 7.59 m/s.
(2) The highest percentage of windward direction is obtained from the south-south-west direction in Antakya. The lowest percentage of windward direction is obtained from the north direction in Bartın.
(3) Weibull shape parameter k varies between 1.54 and 1.86, while scale parameter c varies between 2.52 m/s and 8.34 m/s.
(4) The highest annual mean power density is obtained as 1257 W/m^2 in August for Balıkesir while has the lowest value is calculated as 7.01 W/m^2 in January for Bartın.
(5) The maximum energy output is found for wind turbine with a capacity of 2500 kW (Nordex N80) in Balıkesir station while the minimum energy output is obtained for wind turbine with a capacity of 600 kW (Suzlon S52) in Bartın.
(6) The current study is an investigation study in order to estimate wind energy potential of the 12 locations in coastal regions of Turkey. It is seen that the localities situated in the Marmara region are characterized by a good wind potential compared to other coastal localities.

Nomenclature

A	sweep area (m^2)
c	Weibull scale parameter (m/s)
C_f	capacity factor
E_{out}	energy output (kWh/year)
h	height (m)
k	Weibull shape parameter
P	power of wind per unit area (W/m^2)
P_r	rated power (W/m^2)
v	wind speed (m/s)
V_m	annual mean speed (m/s)
V_E	annual energy speed (m/s)
V_F	annual wind energy available (m/s)
$\bar{v}$	mean wind speed (m/s)
v_i	wind speed in the stage i (m/s)
v_r	rated wind speed (m/s)
α	power law exponent
ρ	air density (kg/m^3)
Γ	gamma function
σ	standard deviation

References

[1] Akdağ SA, Dinler A. A new method to estimate Weibull parameters for wind energy applications. Energy Conversion and Management 2009;50:1761–6.
[2] Oğulata RT. Energy sector and wind energy potential in Turkey. Renewable and Sustainable Energy Reviews 2003;7:469–84.
[3] IEA (International Energy Agency). 2004 Energy Balances for Turkey. Accessed from http://www.iea.org.
[4] Erdogdu E. On the wind energy in Turkey. Renewable and Sustainable Energy Reviews 2009;13:1361–71.
[5] Kone AC, Buke T. An Analytical Network Process (ANP) evaluation of alternative fuels for electricity generation in Turkey. Energy Policy 2007;35:5220–8.
[6] Makkawi A, Tham Y, Asif M, Muneer T. Analysis and inter-comparison of energy yield of wind turbines in Pakistan using detailed hourly and per minute recorded data sets. Energy Conversion and Management 2009;50:2340–50.
[7] Pallabazzer R. Parametric analysis of wind siting efficiency. Journal of Wind Engineering and Industrial Aerodynamics 2003;91:1329–52.
[8] Carta JA, Ramírez P, Velázquez S. A review of wind speed probability distributions used in wind energy analysis. Renewable and Sustainable Energy Reviews 2009;13:933–55.

[9] Himri Y, Himri S, Boudghene Stambouli A. Assessing the wind energy potential projects in Algeria. Renewable and Sustainable Energy Reviews 2009;13: 2187–91.
[10] Mahmoudi H, Spahis N, Goosen MF, Sablani S, Abdul-wahab SA, Ghaffour N, et al. Assessment of wind energy to power solar brackish water greenhouse desalination units: a case study from Algeria. Renewable and Sustainable Energy Reviews 2009;13:2149–55.
[11] Gökçek M, Genç MS. Evaluation of electricity generation and energy cost of wind energy conversion systems (WECSs) in Central Turkey. Applied Energy 2009;86:2731–9.
[12] Belu R, Koracin D. Wind characteristics and wind energy potential in western Nevada. Renewable Energy 2009;34:2246–51.
[13] Mostafaeipour A. Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran. Renewable and Sustainable Energy Reviews 2010;14:93–111.
[14] Ahmed Shata AS, Hanitsch R. The potential of electricity generation on the east coast of Red Sea in Egypt. Renewable Energy 2006;31:1597–625.
[15] Gökçek M, Bayülken A, Bekdemir Ş. Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey. Renewable Energy 2007;32:1739–52.
[16] Elamouri M, Ben Amar F. Wind energy potential in Tunisia. Renewable Energy 2008;33:758–68.
[17] Eskin N, Artar H, Tolun S. Wind energy potential of Gökçeada Island in Turkey. Renewable and Sustainable Energy Reviews 2008;12:839–51.
[18] World Wind Energy Report 2008. Report. World Wind Energy Association. February 2009. http://www.wwindea.org/home/images/stories/worldwindenergyreport2008_s.pdf. Retrieved 16-March-2009.
[19] http://www.nordex-online.com.
[20] http://www.suzlon.com.
[21] http://www.vestas.com.